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Risk evaluation of the grain supply chain in China

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ABSTRACT
The food supply chain (GSC) involves multiple links from production to consumption. The interruption of one or more links will lead to supply risks, evolving into food crises. To better guarantee food security, maintain national security, it is essential to improve the structural imbalance of China's food supply. This article innovatively regards trade as an important link in the food supply chain and quantitatively designs 16 indicators from the four links of production, consumption, trade, and circulation to evaluate the food supply chain risks of 30 provinces in China from 2003 to 2019. The results show that: (1) The GSC risk value at the regional scale is generally stable, and the western region is slightly higher than the eastern region. (2) The distribution of risk value shows significant spatial clustering. (3) During the study period, China's grain risk has not changed significantly. The highest average risk is the production link of the supply chain, followed by the distribution and trade links. He also believes that adjusting production, enhancing regional trade, strengthening suitability, and enhancing defensiveness are corresponding measures to improve the food supply chain. It is expected to provide a reasonable reference for government agencies.

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Grain supply chain; food supply chain; grain risk; international trade; epidemics

1. Introduction

In the process from production to consumption, meeting consumer demand for food involves coordination among multiple chains, including production agents, processors, distributors, service providers, storage facilities, and ultimately consumers (Stephen et al. 2012). The grain supply chain (GSC) is the whole process from field to production, involving multiple links such as agriculture, grain processing, grain wholesale, grain retail, and catering (Lang and Ding 2008). GSC meets food demand and transforms from an existing supply chain to a circular supply chain. Lily, Seyed, and Armin (2021) pointed out that the supply chain is a closed loop composed of a continuous sequence structure, and the levels are interconnected. Transmission interruption in one or more aspects of any part of the supply system may cause supply risks. GSC interruption may come from two sources: artificial damage, such as terrorist attacks, labour strikes, etc., and natural damage, such as tsunamis and earthquakes (Yavari and Ajalli 2021), and then may evolve into a food crisis. The main driving force for the shift to a circular supply chain is the material scarcity and attention to several global resource and environmental issues (Rockstrom, Wani, and Oweis 2009; Choi, Lee, and Debbarma 2020) and the inherent economic and business opportunities. As

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the world's largest trading country, China's total imports of agricultural products from the United States in 2020 will reach 162.74 billion yuan, but the COVID-19 pandemic has increased the trade barriers of some grain importing and exporting countries and the stability of the grain supply chain has been affected, and the chain reaction has increased. The 'disconnection risk' of the global supply chain, the emergence of a food supply crisis, global economic and trade tensions, fluctuations in food prices, and uncertain future development trends. Deng's research shows that regional development gradually began to converge after the obvious unbalanced development in the past (Deng et al. 2021). Economic, environmental, and social sustainability issues have attracted attention (Najmuddin, Deng, and Bhattacharya 2018; Song, Xie, and Shen 2021; Kumar et al. 2018). The circular economy provides opportunities to optimise GSC (Managi and Jena 2008; Jain, Jain, and Metri 2018). The State Council has issued several documents to ensure the security of food supply; these documents cover many aspects of food supply, including distribution, production, farmland protection, and food sales. The No. 1 document of the central government in 2021 pointed out that it is necessary to promote structural reforms on the agricultural supply side, stabilise the sown area of grain, and further improve the quality of grain and other agricultural products. At the same time, the core contradictions of Chinese society in the new era are gradually changing. Ensuring the stability, safety, and efficiency of the food supply system has become an important issue facing our country. At present, China's grain supply and demand still face the risk of structural inadequacy and the inability to meet appropriate imports effectively. It is necessary to make full use of international grain sources to adjust surplus and shortages and meet the needs of moderate imports. Trade plays a vital role in the rational allocation of supply and demand between regions and promoting the circulation of factors between regions. With the increasing degree of economic globalisation, the risk adjustment of food becomes more and more critical. Food security is the bottom line for overall security and development, and the issue of food security is a matter of national security guarantee. It is of great significance to study food security at the national and inter-provincial scales. Development geography focuses on the four fields of economy, culture, society, and ecology and uses comprehensive analysis methods to study regional differences. This article attempts to start from the provincial level, comprehensively explore the changes in the risks of the food supply chain from production, circulation, trade, and consumption, and summarise the changes in the risk of the food supply system from the temporal and spatial trends, in order to make relevant decisions: theoretical basis and reference.

2. Literature review

GSC covers a wide range of areas where risks are unavoidable (Tseng et al. 2014). Identifying risks and proposing the best solutions is a critical issue in academia (Zhao et al. 2019). In the food industry system, the optimal allocation of elements is often closely related to GSC, and the identification and assessing potential risks are essential to achieve the optimal allocation of elements. Lang and Ding (2008) used logistics outsourcing as the research object in empirical research and the risk matrix method to evaluate risks from five aspects: technology, management, cooperation, finance, and environment. Mandal et al. (2016) found that integrated logistics capabilities positively impact supply chain collaboration and supply chain visibility. Paciarotti and Torregiani (2021) believes that logistics is a key element that affects the performance of the supply chain and summarises and discusses the two aspects of researchers and practitioners on improving the effectiveness and sustainability of SFSC. Vernier et al. (2021) demonstrated that the use of ICT in the agri-food supply chain could increase the potential and sustainability of the supply chain. Lang and Ding (2008) found that technology and cooperation have the highest risks. Robert et al. (1998) believes that cooperation between different companies can improve the information asymmetry in the supply chain. Ali et al. (2019) analyzed the GSC risks in the context of labour quality, leadership style, and management system. Edmond and Soliman (2017) determined that the probability, impact, and threshold of risk in GSC vary. In terms of supply chain management (SCM), Bui et al.

(2020) reviewed the results of previous studies and believed that differences in fairness between regions are the key to sustainable supply chains. Tseng et al. (2021) found that blockchain, cash flow shortage, reverse factoring, risk assessment, and triple bottom line (TBL) play an important role in supply chain finance (SCF). Policy cyclicality and fluctuations in customer demand are high risks. Cen and Zhuang (2017) explored the hazards of food additives to food security around the government, farmers, and production enterprises, and found that the price of food is positively correlated with the punishment of food additives. In terms of policy mechanism research, many countries have implemented policy interventions in agricultural product markets. For example, the United States (US) has directly intervened in the agricultural product market since the 1920s. It has effectively reduced risks related to nature, the market, and the environment through policies such as price support, direct farmers' subsidies, and agricultural insurance premium subsidies. Policy. Food subsidy policy research mainly focuses on subsidy objects, subsidy standards, subsidy scale, and subsidy methods, including agricultural insurance and machinery purchase subsidies. Many studies have focused on the minimum purchase price system as a subsidy for food and agriculture. Research on the impact of food subsidies on production and income is polarised (Heerink 2006). In the long run, the experience and practices of promoting agricultural development, such as institutional reforms, technological progress, market reforms, and provision of agricultural inputs, will remain the key to ensuring food security (Wang and Li 2017). For the GSC evaluation, León-Bravo, Caniato, and Caridi 2021 focused on the micro-supply system of a single company and applied the stakeholder theory to evaluate the supply chains of 12 Italian food companies. A similar study includes Schrobback, Rolfe, and Star (2020) on the Australian agricultural subdivisions. Evaluation of the GSC, Yontar and Ersz (2021), is based on the structural equation model to evaluate the sustainability of the fresh vegetable and fruit supply chain. In summary, scholars have conducted much research on policy support and microeconomic factors of food risk and policy support for risk mitigation. However, such research mainly focuses on specific components or links of the broader supply chain and tends to affect efficiency caused by a particular aspect of the supply chain system. Compared with micro-industry or micro-economic organisations, there is a lack of risk assessment for the entire food system based on the national scale. Compared with a particular link in the GSC, based on comprehensive analysis methods, the overall supply chain evaluation is relatively lacking. In terms of food, there are few comprehensive studies on the hazards and risks of multiple or all components of the GSC.

The COVID-19 epidemic has had a significant impact on the international trade environment and GSC. Brewin (2020) assessed the epidemic's impact on the Canadian grain and oilseed supply chain and concluded that the epidemic would have a short-term impact on the distribution and demand downstream of the supply chain. Chen and Mao (2020) believe that the trade barriers established during the epidemic will form a 'fault line' in the global food system. Kerr (2020) believe that the pandemic will bring unprecedented pressure to the global GSC. Jha et al. (2021) quantified the impact of COVID-19 on the production of major food crops and its ripple effect on the national economy and related policies, aiming to solve or manage the impact of COVID-19 on the food system. Koppenberg et al. (2021) assessed the impact of the food export ban on global trade before and after the epidemic. Most of these studies focused on one or two aspects of changes in the international trade environment and lacked a comprehensive risk assessment of GSC under the dual background of changes in the global trade environment and the epidemic's impact. At the same time, as China gradually opens to the outside world, inter-regional trade exchanges are becoming more frequent. Trade liberalisation can increase industrial productivity (Pavcnik 2002) and form a comparative industrial advantage (Yeaple 2005). However, at the same time, it will seriously affect the domestic economic ecology, including employment (Blanco et al. 2020) and income (Distefano et al. 2017). To sum up, the special position of trade in the entire circulation system has an important impact on the GSC, and the spread of the epidemic has spread to many countries and regions. Circulation emphasises the process of commodity flow, while trade emphasises the behaviour of commodity exchange. The strategy proposed by the Chinese government to 'accelerate the construction of a new development pattern with domestic and international double cycles as the main body' and the establishment of trade zones have intensified changes in the domestic and international trade environment, and trade behaviour has more prominent effects on commodity flows. The development of inter-provincial trade has promoted the division of labour and collaboration between different regions and departments, accelerated the flow of factors between provinces, optimised resource allocation efficiency, and improved domestic market integration. The contribution of trade to industrial stability and the integrity of the supply chain seems to be more prominent, and the development of inter-provincial trade appears to be particularly important.

This study believes that trade behaviours, along with the implementation of China's domestic and international dual-cycle strategy, have gradually increased their impact on GSC risks. Internally, the domestic trade cycle can be used to adjust the provincial grain structure, and the international cycle will import moderately to the food supply. The integrity of the chain and risk control play an important regulatory role. This article is based on a comprehensive analysis method to discuss food security issues from the four aspects of production, consumption, circulation, and trade in the food supply system. The contribution of this article to previous studies is that the research scale has been expanded from micro-enterprises or sub-industries to the macro-provincial food supply system, which has strengthened the role of trade on food security in the entire GSC. The evaluation system is relatively. The results of previous studies are more comprehensive. The rest of this article is arranged as follows. Section 2 introduces the composition, research methods, and data sources of the indicator system to assess GSC risks. The third section analyzes the temporal and spatial changes of GSC risks in 30 provinces/regions in China from the four key chains of production, circulation, consumption, and trade. Finally, Section 4 summarises and discusses the deficiencies of the research.

2. Indicators and methods

2.1. Index system for the evaluation of grain supply chain risk

The GSC covers activities from producing bulk grain and raw materials from agricultural products to fresh grain, and includes production, manufacturing, distribution, sales, and consumption (Wells and Edwards 2004). With the surge in demand for personalised agricultural products, the focus of the GSC has shifted from market building to interchain relationship coordination (Mccord et al. 1998). Thus, the interchain relationship encompasses many chains from production to manufacturing, distribution, retail, trade, and consumption. Risku and Maeenpaeae (2007) describes the risk of grain production in Finland based on the input–output and material flow approach and argues that the average unit price of grain and the quantity and cost of grain production and consumption would affect the development of the grain industry. Wang (2016) analyzes the risk of meteorological disasters in South China based on provincial crop yield data and a probability density functional algorithm. Grain distribution ensures the transfer of grain from production to consumption. The whole process creates a heavy dependence on infrastructure. The public distribution system becomes a key capacity area in the GSC (Bhagwat and Raut 2012). Grain consumption serves as the endpoint of the GSC, with different purchasing decisions influencing the choice to consume (Bourlakis and Weightman 2007). The quality of agricultural products and the price of grain consumption have key impacts on willingness to consumer. Chaudhuri et al. (2016) argues that adequate investment in technology can significantly reduce risk and thus increase profitability for the grain trade. The essential elements of technology and capital, which are acquired by trade between different regions, guarantee efficient production, distribution, and consumption in the grain supply system. Given this, this paper selects the four-key links in the supply chain of production, distribution, consumption, and trade to build an index system to evaluate GSC risk.

This paper analyzes the metadata of previous research results and selects the high-frequency indicators in the four critical chains as the basis of the GSC risk evaluation index system (Table 1). Changes in the international trade environment and the new crown pneumonia epidemic have a direct impact on foreign investment, which in turn affects the domestic grain import and export trade, causing changes in the industrial structure over a long period and leading to changes in the industrial supply chain. In the index system, the production chain includes six secondary indicators: per capita grain production, grain sown area, disaster area, agricultural producer price index, agricultural population, and grain production. The distribution chain considers changes in the international trade environment and changes in grain prices contains four secondary indicators: the retail grain price index, the change in the cost of grain distribution, railroad mileage, and road mileage. The consumption chain includes three secondary indicators: gross domestic product per capita, disposable income per capita, and the grain consumption price index. The trade chain is the most directly affected by the international environment and the new crown pneumonia epidemic. Three secondary indicators are selected: the value added of the agriculture, forestry, animal husbandry, and fishery industry, the number of foreign-invested enterprises, and the total investment of foreign-invested enterprises. As each indicator contributes to the risk of the GSC in different directions, effective differentiation is needed. For per capita grain possession, grain sown area, agricultural population, and grain production, the higher the initial value, the lower is the risk to grain production. The producer price index of agricultural products is the price level of agricultural products sold directly by producers, which is consistent with the consumer price index of grain and the variable cost of grain distribution. The railroad and road mileages represent the level of grain distribution infrastructure that has been constructed, while the retail price

Table 1. Index system for the risk evaluation of grain supply chain in China.

Target layer	Primary indicators	Secondary indicators	Description of indicators	Expected signs of indicators
Grain supply chain risk composite index (R)	Production (A)	Per capita grain holdings (a1)	Change in unit output	–
		Grain sown area (a2)	Impact of land factor inputs	–
		Disaster area (a3)	Impacts of climate change	+
		Agricultural producer price index for agricultural products (a4)	The impact of international trade environment on the production price of unit products	+
		Agricultural population (a5)	Human capital input	–
		Grain production (a6)	Overall output	–
	Distribution (B)	Retail grain price index (b1)	Changes in the international trade environment has an impact on distribution prices	+
		Variable cost of grain distribution (b2)	Changes in the international trade environment has an impact on market distribution costs	+
		Railroad mileage (b3)	Rail transportation costs	–
		Road mileage (b4)	Road traffic costs	–
	Consumption (C)	GDP per capita (c1)	Regional economic level	–
		Disposable income per capita (c2)	Per capita consumption power	–
		The grain consumption price index for grain (c3)	The impact of the changing international trade environment on the movement of consumer grain prices	+
	Trade (D)	The value added of the agriculture, forestry, animal husbandry and fishery industry (d1)	Changes in the international trade environment	–
		Number of foreign-invested enterprises (d2)		-
		Total investment of foreign-invested enterprises (d3)		-

index of grain and the variable cost of grain distribution represent the distribution price and distribution cost, respectively.

2.2. Method

In this article, we assess many aspects of GSC risk based on the GSC system. The most used risk assessment methods are (1) Analytic Hierarchy Process (AHP). Yontar and Ersz (2021) uses the AHP method to determine the dimensions that affect the sustainability performance of the fresh vegetable and fruit supply chain and Liu et al. (2013) on the supply chain logistics capabilities of food production companies. (2) Principal component analysis method (PCA). Cao and Fan (2017) used principal component analysis to evaluate the green agricultural performance supply chain in 10 cities in Shandong Province and gave countermeasures to improve the effectiveness of the supply chain. (3) Range method. Zhao and Yang (2013) used the range method to evaluate the value of China's total food safety risks through three stages of agricultural production, food processing, and food consumption. (4) TOPSIS method. Liu, Wang, and Wang (2021) used the TOPSIS method to calculate the innovation path index of the smart supply chain (SSC). In addition to this, some scholars have also combined a variety of methods. Wang (2016) combined AHP and fuzzy comprehensive evaluation methods to evaluate GSC safety. In the above methods, AHP relies heavily on empirical judgment and requires much practical experience as the basis. PCA's dimensionality reduction causes the data to lose part of the characteristic values, which is only used in the cross-sectional data. The range method is more dependent on data than AHP and PCA, limiting the data information between 0 and 1, reducing the difference between data. The TOPSIS method is a step further than the extreme value method. The greater the relative closeness between the ideal value and the plan, the better, but the ideal value is affected by the number of indicators, and the research object must be more than two. The entropy method is a comprehensive evaluation method involving multiple indicators and objective assignment. It determines the weight of indicators according to the degree of connection of each indicator or the amount of information provided by each indicator. The research object can be evaluated objectively and accurately (Xie and Wang 2018). In order to scientifically explore the risk transmission mechanism of GSC, this article improves the traditional entropy method and combines the GSC situation of different provinces in the long-term sequence. Specific steps are as follows.

(1) Let the total number of indicator data be m data sets of n years and k provinces, where $a_{\theta ij}$ denotes the jth indicator of province i in the θth year. Then, the original data list matrix R is:

$$R_{nkm} = \begin{Bmatrix} A \\ B \\ C \\ D \end{Bmatrix} = \begin{Bmatrix} a_{\theta ij} \\ b_{\theta ij} \\ c_{\theta ij} \\ d_{\theta ij} \end{Bmatrix} \quad (1)$$

(2) Because the direction and unit of each indicator is different, dimensionless processing is required. We adopt the extreme value method, where a_{min} and a_{max} are the minimum and maximum values of the indicators, respectively, and the formulas are as follows:

$$a_{\theta ij} = \frac{a_{\theta ij} - a_{min}}{a_{max} - a_{min}} \quad (2)$$

$$a_{\theta ij} = \frac{a_{max} - a_{\theta ij}}{a_{max} - a_{min}} \quad (3)$$

(3) To avoid zero and negative values, the dimensionless result is shifted overall by 0.0001 and denoted by $X_{\theta ij}$, and the p-value $P_{\theta ij}$ is calculated with the entropy value e_j. ln(K) is the

logarithm of the sample size K:

$$p_{\theta ij} = \frac{X_{\theta ij}}{\sum_{i=grave;1}^{n} a_{\theta ij}} \tag{4}$$

$$equatione_j = \frac{-1}{\ln(K)} \sum_{i=1}^{j} p \cdot \ln p \quad (5)equation$$

(4) Next, we calculate the coefficient of variation E_j: :

$$E_j = 1 - e_j \tag{6}$$

(5) Then, we determine the weights W_j:

$$W_j = \frac{E_j}{\sum_j E_j} \tag{7}$$

(6) Finally, we determine the score of the composite risk index R for the integrated GSC $R_{\theta i}$: as follows:

$$R_{\theta i} = \sum_j W_j \times p_{\theta ij} \tag{8}$$

2.3. Data sources

The data mainly comes from the official website of the National Bureau of Stistics (https://data.stats.gov.cn/) and the 2004–2020 China Statistical Yearbook. Considering the availability of data, we collected a total of 16 indicators in 4 aspects, namely: production, including per capita grain possession (kg), grain sown area (thousand hectares), disaster area (thousand hectares), agricultural products Producer price index (previous year) = 100), agricultural population (10,000 people), food production (tons). Circulation includes the retail price index of grain (previous year = 100), changes in grain circulation costs, railway mileage (10,000 kilometres), and highway mileage (km). Consumption includes per capita GDP (yuan), per capita disposable income (yuan), and food consumer price index (previous year = 100). Trade includes the added value of agriculture, forestry, animal husbandry and fishery (10,000 yuan), the number of foreign-invested enterprises (a), and the total investment of foreign-invested enterprises (US$ million). The data on grain sown area, railway mileage, highway mileage, number of foreign-invested enterprises, and total investment of foreign-invested enterprises are from the official website of the National Bureau of Statistics (https://data.stats.gov.cn/), and the remaining indicators are from the 'China Statistical Yearbook (2004) – 2020)'. Among them, the affected area, grain output, per capita grain holdings, and added value of agriculture, forestry, animal husbandry, and fishery come from Chapter 12 of the 'China Statistical Yearbook (2004–2020)', and the agricultural population comes from Chapter 2, Agricultural Produce Producer Price Index, Food. The retail price index, and the food consumer price index come from Chapter 5, and the per capita GDP and per capita disposable income come from Chapter 6. The difference between the producer price index of agricultural products (previous year = 100) and the retail grain price index (previous year = 100) is used to measure changes in the cost of grain circulation. Since agricultural population is not directly counted, we use rural population to replace this indicator. The added value of agriculture, forestry, animal husbandry and fishery is represented by the trade volume of the primary industry, reflecting the trade structure of the grain industry. Due to data availability issues, we excluded Tibet, Hong Kong, Macau, and Taiwan.

3. Results

3.1. Changes in interprovincial grain supply chain risks

We find that the GSC risks for production scores were generally stable in China's provinces during 2003–2019, although a few provinces had higher grain production risks relative to others (Table 2). In Hubei, Zhejiang, Anhui, Jiangxi, and Shandong, GSC risk for production fluctuated but increased overall during 2003–2019, indicating that such provinces have uneven inputs (such as land and labour) for grain production. Conversely, in locations including Beijing, Tianjin, Shanghai, Jiangsu, Fujian, Hainan, Gansu, Qinghai, and Xinjiang, the risk of the production link of the GSC tends to be more stable, owing to more stable climates, less mountainous or difficult landscapes, and efficient production factors. In provinces including Inner Mongolia, Heilongjiang, Guangxi, and Chongqing, the production chain appears to be more volatile. Heilongjiang, China's largest grain-producing province, with the highest grain output in the country, has the strongest fluctuations in the production link of the supply chain. The continuous rise in grain unit output is accompanied by a continuous decline in the human capital of the rural population as a result of urbanisation and interprovincial migration and an increase in land factor inputs, represented by the grain sown area. At the same time, the affected grain area is much higher than the national average, and the variation of unit output prices creates greater uncertainty for production in Heilongjiang. At the beginning of the GSC, the production chain is directly affected by climatic conditions, essential factor inputs, and market changes.

Overall, the risk scores for the circulation link of the GSC declined steadily in China's provinces during 2003–2019. However, a few provinces were the exception to this trend, experiencing increasing risks (Table 3). Zhejiang, Fujian, Jiangxi, Hubei, Guangxi, Hainan, Chongqing, Guizhou, and Shaanxi provinces and cities showed a decreasing trend throughout the analysis. In Hebei, Shanxi,

Table 2. Risk score and ranking of the production link of the grain supply chain, by provinces and cities in China, 2003–2019.

Year provinces	2003 scores	2003 ranking	2007 scores	2007 ranking	2011 scores	2011 ranking	2015 scores	2015 ranking	2019 scores	2019 ranking
Beijing	0.0172	5	0.0152	2	0.0115	8	0.0129	5	0.0113	12
Tianjin	0.0180	3	0.0135	10	0.0103	19	0.0127	6	0.0109	14
Hebei	0.0134	23	0.0106	26	0.0084	27	0.0099	24	0.0076	30
Shanxi	0.0143	17	0.0139	6	0.0106	15	0.0121	10	0.0170	2
Inner Mongolia	0.0170	6	0.0125	19	0.0104	17	0.0148	1	0.0134	6
Liaoning	0.0133	24	0.0134	12	0.0096	22	0.0130	3	0.0092	26
Jilin	0.0137	22	0.0108	25	0.0086	26	0.0097	25	0.0094	25
Heilongjiang	0.0190	1	0.0133	13	0.0062	29	0.0071	29	0.0201	1
Shanghai	0.0167	9	0.0143	3	0.0115	9	0.0131	2	0.0107	17
Jiangsu	0.0145	16	0.0102	28	0.0088	24	0.0099	23	0.0083	29
Zhejiang	0.0131	25	0.0122	20	0.0105	16	0.0107	19	0.0115	10
Anhui	0.0137	21	0.0103	27	0.0087	25	0.0078	28	0.0109	15
Fujian	0.0147	15	0.0132	14	0.0110	13	0.0120	11	0.0103	21
Jiangxi	0.0148	13	0.0117	23	0.0104	18	0.0108	18	0.0146	5
Shandong	0.0108	27	0.0079	29	0.0080	28	0.0094	26	0.0119	9
Henan	0.0141	18	0.0073	30	0.0055	30	0.0041	30	0.0098	24
Hubei	0.0162	12	0.0135	11	0.0111	11	0.0102	22	0.0147	4
Hunan	0.0169	7	0.0143	4	0.0122	6	0.0102	21	0.0132	7
Guangdong	0.0102	29	0.0119	21	0.0100	20	0.0119	12	0.0087	27
Guangxi	0.0140	20	0.0137	9	0.0133	2	0.0112	16	0.0107	18
Hainan	0.0173	4	0.0125	18	0.0126	4	0.0123	8	0.0109	13
Chongqing	0.0140	19	0.0139	8	0.0120	7	0.0104	20	0.0105	19
Sichuan	0.0083	30	0.0110	24	0.0096	21	0.0085	27	0.0086	28
Guizhou	0.0126	26	0.0118	22	0.0146	1	0.0110	17	0.0107	16
Yunnan	0.0107	28	0.0128	17	0.0123	5	0.0117	14	0.0156	3
Shanxi	0.0166	10	0.0140	5	0.0108	14	0.0118	13	0.0120	8
Gansu	0.0148	14	0.0139	7	0.0112	10	0.0129	4	0.0102	23
Qinghai	0.0188	2	0.0154	1	0.0128	3	0.0127	7	0.0114	11
Ningxia	0.0164	11	0.0129	16	0.0110	12	0.0121	9	0.0102	22
Xinjiang	0.0168	8	0.0130	15	0.0089	23	0.0115	15	0.0104	20

Table 3. Risk scores and ranking of the circulation link of the grain supply chain, by provinces and cities in China, 2003–2019.

Year provinces	2003 scores	2003 ranking	2007 scores	2007 ranking	2011 scores	2011 ranking	2015 scores	2015 ranking	2019 scores	2019 ranking
Beijing	0.0072	12	0.0092	2	0.0100	9	0.0088	4	0.0081	4
Tianjin	0.0080	6	0.0104	1	0.0083	14	0.0081	8	0.0086	2
Hebei	0.0045	25	0.0062	19	0.0056	22	0.0037	28	0.0054	17
Shanxi	0.0055	21	0.0064	16	0.0044	26	0.0071	16	0.0051	18
Inner Mongolia	0.0025	29	0.0043	29	0.0044	29	0.0073	14	0.0032	26
Liaoning	0.0033	28	0.0058	22	0.0069	17	0.0077	10	0.0068	8
Jilin	0.0039	26	0.0065	14	0.0062	20	0.0063	22	0.0069	7
Heilongjiang	0.0021	30	0.0036	30	0.0057	21	0.0072	15	0.0063	13
Shanghai	0.0066	17	0.0081	6	0.0105	5	0.0113	1	0.0097	1
Jiangsu	0.0067	16	0.0062	20	0.0073	16	0.0079	9	0.0067	9
Zhejiang	0.0074	8	0.0074	10	0.0085	13	0.0081	7	0.0065	11
Anhui	0.0058	19	0.0066	13	0.0109	3	0.0069	17	0.0048	20
Fujian	0.0085	4	0.0080	7	0.0132	1	0.0067	19	0.0065	12
Jiangxi	0.0086	3	0.0072	11	0.0096	11	0.0064	20	0.0048	19
Shandong	0.0069	14	0.0054	24	0.0036	30	0.0033	29	0.0031	27
Henan	0.0055	22	0.0043	28	0.0044	28	0.0073	13	0.0027	29
Hubei	0.0071	13	0.0055	23	0.0099	10	0.0039	27	0.0027	28
Hunan	0.0048	24	0.0049	26	0.0089	12	0.0033	30	0.0035	25
Guangdong	0.0056	20	0.0065	15	0.0080	15	0.0064	21	0.0041	23
Guangxi	0.0092	2	0.0064	17	0.0103	6	0.0046	25	0.0055	16
Hainan	0.0093	1	0.0084	5	0.0126	2	0.0075	12	0.0073	6
Chongqing	0.0074	11	0.0077	8	0.0101	7	0.0075	11	0.0048	21
Sichuan	0.0052	23	0.0047	27	0.0044	27	0.0047	24	0.0025	30
Guizhou	0.0082	5	0.0067	12	0.0100	8	0.0068	18	0.0041	22
Yunnan	0.0066	18	0.0051	25	0.0054	24	0.0039	26	0.0039	24
Shanxi	0.0079	7	0.0062	21	0.0048	25	0.0095	2	0.0057	15
Gansu	0.0068	15	0.0075	9	0.0066	19	0.0062	23	0.0060	14
Qinghai	0.0074	10	0.0085	4	0.0055	23	0.0087	5	0.0074	5
Ningxia	0.0074	9	0.0087	3	0.0106	4	0.0092	3	0.0083	3
Xinjiang	0.0034	27	0.0063	18	0.0068	18	0.0086	6	0.0065	10

Inner Mongolia, Zhejiang, Anhui, Shandong, Henan, Hunan, Guangdong, Sichuan, Yunnan, and Gansu provinces, the risk of the circulation link tended to be stable and less volatile during 2003–2019. Risks to grain supply circulation tended to arise in Beijing, Tianjin, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Qinghai, Ningxia, Xinjiang, and other provinces and cities during 2003–2019, and involved more minor fluctuations. The above three trend types can be roughly divided into two categories. One category is the risk experienced by the more economically developed provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, and Hainan, in which there is limited scope to increase the growth of railroad and road mileage. Consequently, the risk to the circulation link of the GSC arises from changes in the cost of grain circulation and the retail price index of grain. The second category is the risk arising from changes in transportation costs (railroad and road mileage), affecting provinces including Guizhou, Yunnan, Xinjiang, and Ningxia, where unique geographical features and a weak economic base seriously hinder the construction of transportation infrastructure.

The overall volatility of the consumption link of the GSC in China's provinces during 2003–2019 was relatively large, with Yunnan and Xinjiang showing the most significant fluctuations (Table 4). The per capita GDP and disposable income of residents in Yunnan and Xinjiang are lower than the national average, and the consumer grain price index of residents fluctuates to different degrees in both provinces. The regional level of economic development and per capita consumption capacity are low and do not provide high consumption. The fluctuations in the consumer grain prices of residents indicate that the price of consumer grain products and services purchased by households has changed significantly, which has become a source of risk for Yunnan and Xinjiang in the consumption segment of the GSC. In contrast, Beijing, Tianjin, Liaoning, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong, and Ningxia are more stable owing to their higher regional economic

Table 4. Risk scores and ranking of the consumption link of the grain supply chain, by provinces and cities in China, 2003–2019.

Year provinces	2003 scores	2003 ranking	2007 scores	2007 ranking	2011 scores	2011 ranking	2015 scores	2015 ranking	2019 scores	2019 ranking
Beijing	0.0012	29	0.0026	28	0.0017	28	0.0012	30	0.0014	30
Tianjin	0.0039	27	0.0040	27	0.0013	29	0.0029	28	0.0054	20
Hebei	0.0052	20	0.0044	25	0.0072	12	0.0092	1	0.0062	7
Shanxi	0.0053	19	0.0070	11	0.0080	5	0.0079	8	0.0043	27
Inner Mongolia	0.0058	10	0.0071	10	0.0051	23	0.0037	27	0.0057	14
Liaoning	0.0054	16	0.0060	19	0.0039	25	0.0051	22	0.0054	19
Jilin	0.0051	22	0.0066	14	0.0062	17	0.0063	17	0.0070	1
Heilongjiang	0.0048	23	0.0064	16	0.0068	15	0.0072	9	0.0065	5
Shanghai	0.0006	30	0.0016	30	0.0010	30	0.0013	29	0.0020	29
Jiangsu	0.0039	25	0.0042	26	0.0037	26	0.0050	24	0.0043	26
Zhejiang	0.0032	28	0.0024	29	0.0033	27	0.0057	20	0.0042	28
Anhui	0.0063	7	0.0057	21	0.0072	11	0.0083	5	0.0056	18
Fujian	0.0053	18	0.0050	22	0.0069	14	0.0058	19	0.0045	25
Jiangxi	0.0074	1	0.0068	12	0.0087	3	0.0064	13	0.0052	21
Shandong	0.0056	15	0.0061	18	0.0060	18	0.0062	18	0.0057	17
Henan	0.0069	4	0.0072	9	0.0056	22	0.0064	14	0.0057	15
Hubei	0.0061	8	0.0073	3	0.0057	21	0.0085	3	0.0051	23
Hunan	0.0072	2	0.0073	4	0.0084	4	0.0050	23	0.0057	16
Guangdong	0.0040	24	0.0046	24	0.0046	24	0.0043	26	0.0045	24
Guangxi	0.0056	14	0.0058	20	0.0073	9	0.0068	10	0.0065	6
Hainan	0.0072	3	0.0067	13	0.0089	2	0.0056	21	0.0058	12
Chongqing	0.0053	17	0.0047	23	0.0079	7	0.0044	25	0.0051	22
Sichuan	0.0057	12	0.0072	6	0.0071	13	0.0081	6	0.0058	13
Guizhou	0.0066	6	0.0072	5	0.0096	1	0.0090	2	0.0058	11
Yunnan	0.0052	21	0.0065	15	0.0073	8	0.0063	16	0.0069	2
Shanxi	0.0068	5	0.0072	8	0.0059	20	0.0083	4	0.0059	10
Gansu	0.0059	9	0.0072	7	0.0072	10	0.0067	11	0.0067	3
Qinghai	0.0057	11	0.0075	1	0.0064	16	0.0080	7	0.0066	4
Ningxia	0.0057	13	0.0063	17	0.0080	6	0.0067	12	0.0060	9
Xinjiang	0.0039	26	0.0075	2	0.0059	19	0.0064	15	0.0061	8

development level and the intense consumption levels of residents. The stability of the consumer grain price index also plays a role in guaranteeing that the consumption link of the GSC is at a lower risk level. In provinces including Shanxi, Henan, Hubei, Chongqing, and Guizhou, the risk associated with the consumption link in the GSC has declined gradually, owing to local economic policies to stimulate consumption and stability of consumer prices of grain for residents.

Turning to the trade link in the GSC, the overall volatility for China's provinces during 2003–2019 was relatively low, although there are still a few provinces and cities, such as Beijing and Tianjin, where the trade link risks are at a high level (Table 5). The risks associated with the trade link of the GSC in Liaoning, Jilin, Shanghai, and Zhejiang have rebounded. Heilongjiang, Hubei, Hunan, Guangxi, Guizhou, Yunnan, Shanxi, and other provinces have seen a steady decline in trade link risk. Among all provinces, the trade link risk is highest in Qinghai and Ningxia, both of which are remote inland provinces, with production risks triggered by climate, land, and other factor inputs. So, this will result in differences in industrial trade structure compared with other regions, reduced attractiveness to foreign investors, a relatively small number of enterprises, and low investment levels. Overall, the trade risk ranking of China's provinces has not changed dramatically throughout the analysis. In general, the trade risk of the eastern (mainly the coastal) provinces is much lower than that of the western provinces because of the former's relatively high degree of openness, the 'One Belt, One Road' policy, and several other factors, including maritime trade and seed and the free trade zones, which ensure profitable foreign investment, and the high value-added of the agriculture, forestry, animal husbandry, and fishery industry.

Considering the complete or comprehensive GSC, risk has tended to be stable in China's provinces and cities during our analysis period, 2003–2019, although individual provinces, including Tianjin, Yunnan, and Shanxi, continue to have increasing risks (Table 6). Tianjin is in a coastal

Table 5. Risk score and ranking of the trade link of the grain supply chain, by provinces and cities in China, 2003–2019.

Year provinces	2003 scores	2003 ranking	2007 scores	2007 ranking	2011 scores	2011 ranking	2015 scores	2015 ranking	2019 scores	2019 ranking
Beijing	0.0062	12	0.0069	12	0.0066	13	0.0063	18	0.0073	6
Tianjin	0.0062	11	0.0069	10	0.0070	7	0.0073	7	0.0077	3
Hebei	0.0047	23	0.0056	21	0.0051	23	0.0058	21	0.0049	23
Shanxi	0.0066	3	0.0075	4	0.0071	6	0.0077	5	0.0074	4
Inner Mongolia	0.0062	10	0.0070	9	0.0066	12	0.0072	10	0.0066	11
Liaoning	0.0047	22	0.0054	23	0.0052	22	0.0057	23	0.0058	16
Jilin	0.0059	15	0.0068	14	0.0066	11	0.0072	11	0.0070	8
Heilongjiang	0.0059	14	0.0068	15	0.0063	16	0.0066	15	0.0054	20
Shanghai	0.0047	21	0.0049	27	0.0048	26	0.0043	27	0.0064	12
Jiangsu	0.0024	29	0.0018	29	0.0018	29	0.0018	29	0.0027	29
Zhejiang	0.0045	24	0.0051	26	0.0051	24	0.0055	25	0.0055	17
Anhui	0.0054	18	0.0064	17	0.0060	18	0.0064	17	0.0054	19
Fujian	0.0045	27	0.0055	22	0.0054	19	0.0058	22	0.0054	21
Jiangxi	0.0057	16	0.0066	16	0.0064	15	0.0069	14	0.0063	14
Shandong	0.0029	28	0.0037	28	0.0034	28	0.0039	28	0.0028	28
Henan	0.0045	26	0.0051	25	0.0046	27	0.0054	26	0.0039	26
Hubei	0.0052	19	0.0060	19	0.0054	20	0.0058	20	0.0046	25
Hunan	0.0051	20	0.0058	20	0.0054	21	0.0060	19	0.0047	24
Guangdong	0.0008	30	0.0012	30	0.0015	30	0.0017	30	0.0008	30
Guangxi	0.0056	17	0.0063	18	0.0060	17	0.0066	16	0.0052	22
Hainan	0.0064	6	0.0069	13	0.0072	5	0.0077	4	0.0072	7
Chongqing	0.0063	7	0.0073	6	0.0069	8	0.0073	8	0.0068	9
Sichuan	0.0045	25	0.0053	24	0.0050	25	0.0056	24	0.0037	27
Guizhou	0.0065	5	0.0075	5	0.0072	4	0.0073	9	0.0061	15
Yunnan	0.0060	13	0.0069	11	0.0066	14	0.0069	13	0.0055	18
Shanxi	0.0063	8	0.0071	8	0.0067	10	0.0071	12	0.0063	13
Gansu	0.0066	4	0.0076	3	0.0073	3	0.0077	3	0.0073	5
Qinghai	0.0070	1	0.0079	1	0.0077	1	0.0082	1	0.0080	1
Ningxia	0.0069	2	0.0079	2	0.0077	2	0.0082	2	0.0080	2
Xinjiang	0.0062	9	0.0073	7	0.0069	9	0.0074	6	0.0066	10

region and is one of the central cities in the Beijing–Tianjin–Hebei region and the Bohai Sea economic circle. Urbanisation and land development for local industries have resulted in limited arable land remaining. Compared with other provinces, a lower value-added for the agriculture, forestry, animal husbandry, and fishery industry, a smaller grain sown area, and fewer trade and production links. All these factors have resulted in the shortcomings of Tianjin's GSC. Yunnan is in a mountainous region, the Yunnan–Guizhou Plateau, and 94% is mountainous. Its goal of being a 'national ecological civilisation leader' and a policy of returning farmland to forest and grassland mean that Yunnan is giving up many of the large slopes that constitute its arable land. In addition, there is a gap between the economic development level of Yunnan Province and other provinces. Shanxi is on the Loess Plateau, with regional gullies and ravines, limiting the production link and placing constraints on the distribution link of the GSC. In addition, the lack of foreign investment restricts the development of the grain trade links in Shanxi. There is a gradual downward trend in the risk rating of the GSC in Hainan, Guangxi, Hubei, Hunan, and Shanxi. For example, the grain industry structure is imbalanced in Hainan, but the positive externalities offset this because of Hainan's location in the free trade zone and the Pearl River Delta, which offers agglomeration benefits. Consequently, the risks to its GSC remain low overall.

3.2. Spatial pattern of interprovincial grain supply chain risk

To explore the spatial pattern of GSC risk in China, we calculate the average value of GSC risk in each province (Figure 1). There are prominent characteristics of spatial differentiation in the four links of the supply chain, production, distribution, consumption, and trade. Regarding the production link, the risk is higher in the north than in the south and in the northwest than in the

Table 6. Comprehensive risk score and ranking of grain supply chain risk, by provinces and cities in China, 2003–2019.

Year Provinces	2003 Scores	2003 Ranking	2007 Scores	2007 Ranking	2011 Scores	2011 Ranking	2015 Scores	2015 Ranking	2019 Scores	2019 Ranking
Beijing	0.0318	15	0.0339	9	0.0298	15	0.0291	20	0.0281	15
Tianjin	0.0360	6	0.0348	5	0.0270	21	0.0311	11	0.0326	4
Hebei	0.0277	25	0.0267	26	0.0262	23	0.0287	22	0.0240	25
Shanxi	0.0317	16	0.0349	4	0.0302	14	0.0348	4	0.0338	2
Inner Mongolia	0.0315	17	0.0308	19	0.0265	22	0.0329	9	0.0289	13
Liaoning	0.0267	27	0.0306	20	0.0256	25	0.0316	10	0.0273	18
Jilin	0.0285	22	0.0309	18	0.0276	19	0.0295	17	0.0303	9
Heilongjiang	0.0318	14	0.0302	21	0.0250	26	0.0281	24	0.0383	1
Shanghai	0.0286	21	0.0289	22	0.0279	18	0.0300	14	0.0287	14
Jiangsu	0.0276	26	0.0224	30	0.0216	28	0.0246	26	0.0220	28
Zhejiang	0.0283	24	0.0272	25	0.0273	20	0.0300	15	0.0278	17
Anhui	0.0312	18	0.0289	23	0.0328	9	0.0294	18	0.0268	23
Fujian	0.0329	13	0.0317	16	0.0364	6	0.0304	13	0.0267	24
Jiangxi	0.0365	4	0.0322	14	0.0351	7	0.0305	12	0.0309	8
Shandong	0.0263	28	0.0231	29	0.0210	29	0.0228	30	0.0234	26
Henan	0.0310	19	0.0239	28	0.0201	30	0.0231	29	0.0221	27
Hubei	0.0347	7	0.0324	12	0.0322	12	0.0283	23	0.0270	21
Hunan	0.0340	10	0.0322	13	0.0349	8	0.0245	27	0.0271	19
Guangdong	0.0206	30	0.0242	27	0.0241	27	0.0243	28	0.0181	30
Guangxi	0.0343	8	0.0322	15	0.0368	5	0.0292	19	0.0278	16
Hainan	0.0402	1	0.0344	7	0.0412	2	0.0330	8	0.0312	7
Chongqing	0.0330	12	0.0335	10	0.0370	4	0.0296	16	0.0271	20
Sichuan	0.0237	29	0.0283	24	0.0262	24	0.0269	25	0.0206	29
Guizhou	0.0339	11	0.0333	11	0.0415	1	0.0342	5	0.0269	22
Yunnan	0.0284	23	0.0313	17	0.0315	13	0.0289	21	0.0319	6
Shanxi	0.0376	3	0.0345	6	0.0281	17	0.0367	2	0.0299	11
Gansu	0.0341	9	0.0361	2	0.0323	11	0.0336	7	0.0302	10
Qinghai	0.0389	2	0.0394	1	0.0325	10	0.0376	1	0.0334	3
Ningxia	0.0364	5	0.0359	3	0.0374	3	0.0362	3	0.0324	5
Xinjiang	0.0304	20	0.0341	8	0.0285	16	0.0339	6	0.0297	12

southeast. Among the provinces, the risk values are highest in Qinghai and Inner Mongolia and lowest in North China and Sichuan. Northeast and southeast China fall in the middle in terms of relative risk levels for the production link. Turning to the circulation link in the chain, risk shows relatively average spatial distribution characteristics, and the high-risk values are sporadically distributed, including in Qinghai, Ningxia, Beijing, Tianjin, and Hainan. The risk values of Ningxia, Shanxi, Jilin, Liaoning, and the southeastern coastal provinces are in the middle, and other areas have lower risk values. For the consumption link in the chain, risk values are generally high in the whole of China, with only Inner Mongolia, Liaoning, and southeast coastal provinces having lower risk levels. For the trade link in the supply chain, the spatial pattern is not obvious. The risk values for North China, Guangdong, and Sichuan are lower compared with other regions, particularly Qinghai, Gansu, and Ningxia in the north. The comprehensive GSC risk in China shows obvious spatial differentiation characteristics (Figure 2). Overall, the risk value for the northern part of China is slightly higher than that of the southern region, and the risk value of the western region is slightly higher than that of the eastern region. In addition, the distribution of risk values shows obvious characteristics of spatial aggregation. The comprehensive risk is higher in Qinghai, Gansu, and Ningxia and lowers in Hebei, Shandong, Henan, Jiangsu, and Anhui. The risk value of Inner Mongolia and northeast China is in the middle. To a certain extent, GSC risk is closely related to physical and geographical conditions. To reduce the GSC risks, it is necessary to study the natural factors of different regions and adopt different promotion strategies according to local conditions.

3.3. Changes in the grain supply chain risk

The average GSC risk in China from 2003 to 2019 is shown in Figure 3. The GSC risk is highest in Qinghai. It mainly arises from the production link and the per capita grain possession indexes, grain

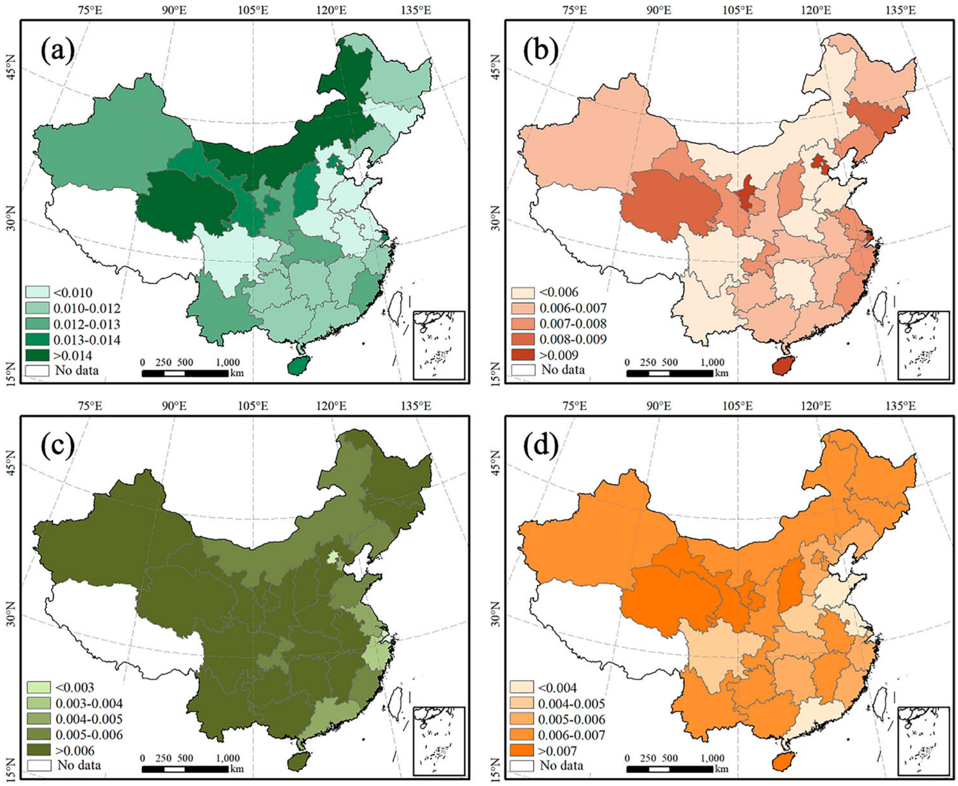

Figure 1. Changes in the spatial pattern of interprovincial average grain supply chain risk on the production (a), distribution (b), consumption (c) and trade (d) links of the supply chain, 2003–2019.

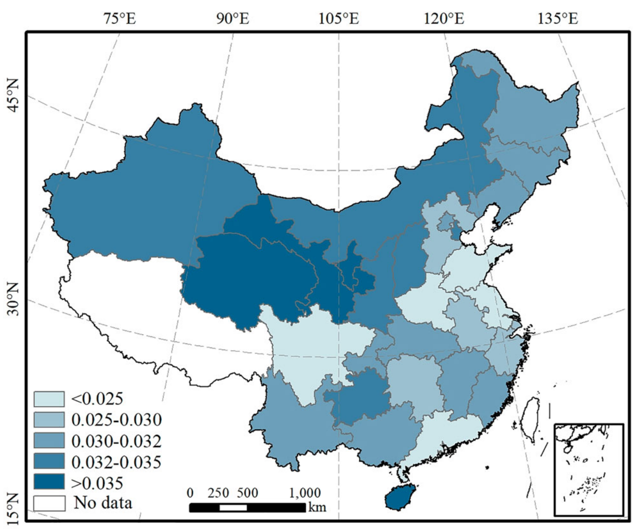

Figure 2. Spatial pattern of interprovincial average grain supply chain risk, 2003–2019.

sown area, and grain output. The GSC risk is lowest in Shandong, where again, the production is the riskiest of the four links in the chain. The provinces with a higher GSC risk are mainly concentrated in the northwest, whereas those with lower risk are mainly located in the eastern coastal areas. Jilin,

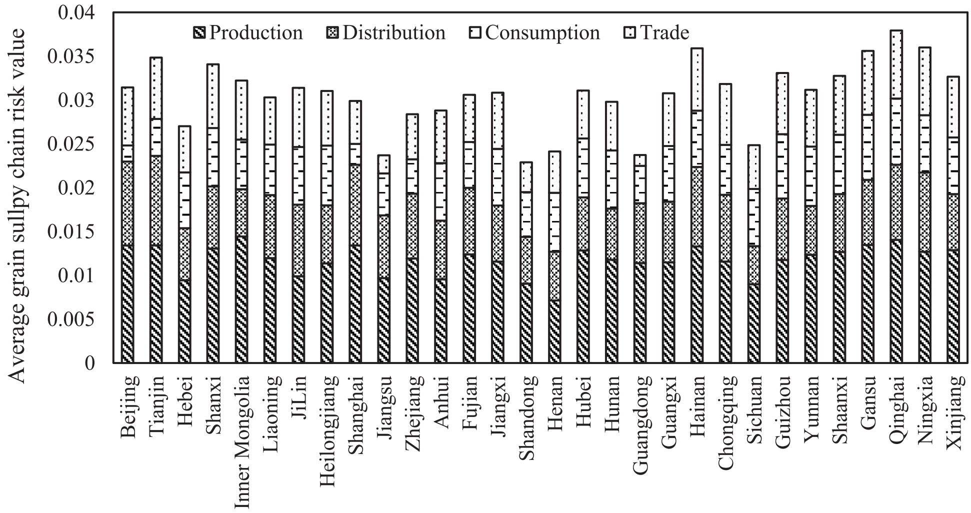

Figure 3. Average grain supply chain risk in China 2003–2019.

Anhui, and Henan are major grain production provinces with low production risk. Sichuan, Yunnan, and Inner Mongolia have low-risk levels because of their low retail price index and grain circulation low variable cost. Jiangsu, Guangdong, and Shandong have many foreign-invested enterprises, and high total foreign-invested funds, so their trade risk is relatively low. The per capita GDP and per capita disposable income of Beijing, Shanghai, and Tianjin are at the forefront of the country, and their consumption risk is low.

The average value of GSC risk fluctuates slightly over the period 2003–2019 (Figure 4). In terms of the shares of the production, circulation, consumption, and trade links within absolute risk, the risk structure remains relatively stable (Figure 5). From a structural point of view, the average ratio of the production link is highest during the period of analysis, followed by the circulation link, with the trade link accounting for the lowest proportion of risk. From the perspective of the trend over time, the GSC risk in China does not change greatly during the period 2003 to 2019. Although the risk of the production link decreased over the period, there were fluctuations, particularly in the risk of the circulation link of the chain. Compared with 2003, the distribution link risk had decreased by

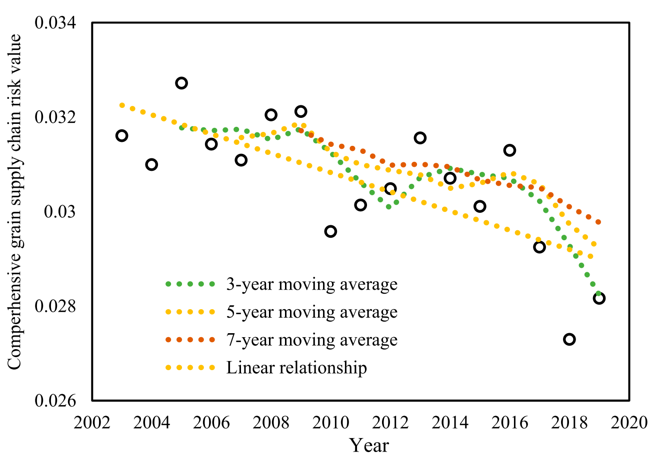

Figure 4. The trend in the average value of grain supply chain risk, 2003–2019.

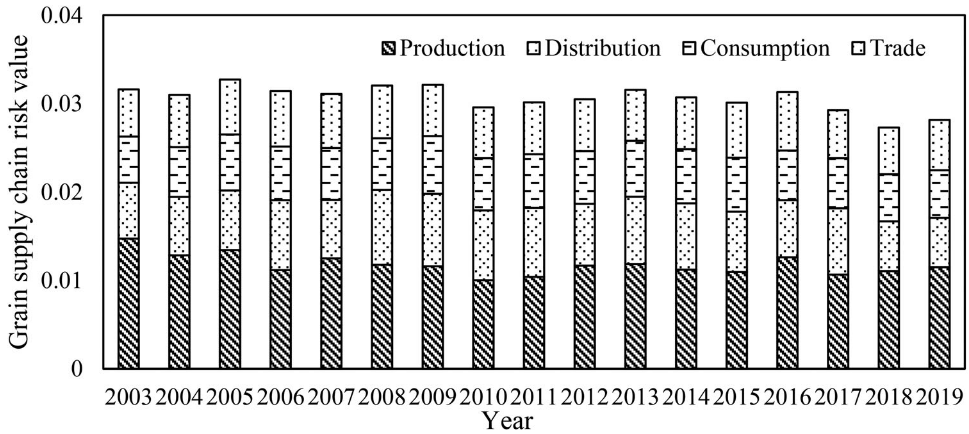

Figure 5. Contribution of the production, circulation, consumption, and trade links to the grain supply chain risk.

2019. There was no apparent trend in terms of the consumption link, although it increased slightly during the period of analysis. In the trade link of the chain, the risk value in 2019 was higher than in 2003, and there were obvious fluctuations over the period.

4. Conclusion and discussion

To determine the weak links of China's GSC, this study builds a GSC evaluation index system based on the four-key links of production, circulation, consumption, and trade explores the risks of China's inter-provincial GSC from 2003 to 2019 and determines the entropy method to calculate the weight of each indicator, and based on socio-economic data, analyze the GSC risks of 30 provinces in China, including the temporal and spatial changes during the analysis period.

(1) From 2003 to 2019, the risk value of China's GSC in the four links of production, circulation, consumption, and trade remained stable. The production risk of individual provinces is higher than other provinces; for example, the GSC risk index of Heilongjiang in 2019 is 0.0201, which is much higher than the 0.0094 of Jilin. Overall, the circulation risk is steadily declining, and a few provinces are on the rise. Taking Beijing as an example, the circulation risk has risen from 0.0072 in 2003 to 0.0081 in 2019, but the overall fluctuation is relatively small.
(2) China's GSC risk presents obvious spatial differentiation characteristics in the four links of production, circulation, consumption, and trade. The total risk value of GSC in northern China is slightly higher than that in the south, and the western part is slightly higher than that in the east. From the perspective of production links, the risk value of the Northwest region is significantly higher than that of the Southeast region. For the distribution link, the risk value presents a relatively even spatial distribution. Except for Inner Mongolia, Liaoning, and the southeast coastal provinces, the risk value of the consumption link is generally higher in the country. Finally, for the trade links in the supply chain, although the risk values of North China, Guangdong, and Sichuan are significantly lower than those of other regions, the spatial characteristics of risks are not prominent.
(3) The distribution of risk value shows obvious spatial aggregation characteristics. Qinghai, Gansu, and Ningxia have higher comprehensive risk values than other provinces, while Hebei, Shandong, Henan, Jiangsu, and Anhui are lower. The risk values of Inner Mongolia and Northeast China are in the middle. From a structural point of view, the average risk rate of my country's GSC production link from 2003 to 2019 is the highest among the four links, followed by the circulation link, and the trade link has the lowest risk ratio.

Food security is an eternal topic. Scholars from all walks of life try to use different methods to demonstrate the importance of food security from different angles. Food security assessment and risk measurement are the two basic angles that have received the most attention. As the foundation of the development of the national economy, the GSC can withstand the impact of various risks and maintain political stability. The process of globalisation also makes food no longer just a commodity. However, the global outbreak of new crown pneumonia has deepened the unsustainability and vulnerability of food security, including supply chain and trade disruption, as well as the resulting increase in unemployment and rising poverty levels (Ifpri 2021). Although different countries have different levels of economic development and national ideologies, they all have different levels of food supply risks, and food risks are widespread. Food security is related to the security of the national economy and people's livelihood. It has the nature of a public product. The public service provided to the country is the ability to provide stable and sufficient food for the people. For China, the relationship between productivity and production is constantly evolving, and the food contradiction has changed from insufficient total food supply to structural imbalance in the food supply. Food security has another layer of particularity for China. The high degree of foreign dependence on the grain market, the government's high attention to food security, and the deep memory of historical famine (the inheritance of the fine tradition of self-reliance) have all made food security become A major strategy. We must firmly hold our jobs in our hands and have sufficient food as support to strengthen our voice and initiative in the international food market. The risk assessment of the GSC can identify the trend of changes in the food risk and provide reasonable suggestions with a reference value for the adjustment of food supply and demand and the reasonable planning of the food structure.

According to the research results of this article, the discussion is carried out in combination with the previous research results. (1) The overall risk of China's GSC remains stable, but individual provinces have higher risks than other provinces. This is due to differences in low-level production factors including natural conditions, such as climate and landform conditions (Hidayat, Rachmawati, and Wahyunin 2021), and the changes in GSC risks are also affected by the transfer of human capital (Farmania, Felix, and Alfredo 2021), population movements between provinces will inevitably be accompanied by changes in the amount of food. In addition, the acceleration of urbanisation has also accelerated the rate of conversion of cultivated land to construction land (Koscica 2014). (2) The risk value of my country's GSC shows obvious spatial differentiation in the four links of production, circulation, consumption, and trade. Research by Yang et al. (2017) pointed out that the spatial differentiation of food production is positively affected by input factors such as rural population, total power of agricultural machinery, fertiliser application, pesticide consumption, rural per capita net income, and grain sown area. It is also affected by rural electricity consumption. Negative impact. Barslund (2007) pointed out that food consumption is heterogeneous across regions, which is linearly related to per capita net income (Worsley et al. 2003). Public health emergencies can also change the frequency and types of food consumption (Giacalone et al. 2021). (3) The distribution of risk value in the GSC shows obvious spatial aggregation characteristics. Since food planting is restricted by innate natural production factors such as land, water, and climate, and with the continuous injection of production factors, such as infrastructure, technology, and capital, there are various organisations at different scales and levels (Miranda, Azzaro, and Aguilar 2017).

The research of Qi, Vitousek and Liu 2015 found that natural disasters (floods, droughts, freezing and frost), resource constraints, input constraints and increased food demand are dangerous sources that may lead to food insecurity. This article also validates this view. In addition, Wang (2010)'s research shows that climate change will significantly impact food security, but food prices have no impact on China's food security. This article believes that climate change will pose a production risk to food security, but food prices will also make food security unsustainable (International C 2011), especially when the trading environment is affected by emergencies such as the new crown epidemic (Jayson, Felix, and Amanda 2021). Changes in food prices affect producer prices in the upper reaches of the GSC, retail prices in the middle reaches, and consumer prices in the lower reaches of the GSC. They are in a chain of mutual influence. This paper also finds that the GSC risk is affected by the price of food circulation, the variable cost of circulation, and the cost of transportation. This is because food circulation is an important medium for regulating food production and food consumption (Jiang et al. 2021), and infrastructure is perfected. It can reduce the fixed costs in the adjustment of grain supply and demand. While the changes in grain circulation prices directly affect grain retail prices, they also adjust the variable costs of grain circulation. In addition, this article also regards the grain trade structure, grain trade volume, and grain trade scale as important factors affecting the risks of the GSC. The role of construction and development is becoming more and more important (Mohsen 2020).

Food security is an important foundation and guarantee for the healthy development of the country. The optimisation of GSC is an important part of ensuring food security. This article analyzes China's GSC experience changes from 2003 to 2019, which has two implications. In theory, this article strengthens the role of trade in the GSC, and evaluates it from three aspects: trade structure, trade volume, and trade scale. It is a supplement and development to the existing GSC evaluation system. In practice, this article analyzes the changes in the experience of China's provincial GSC in detail from both time and space, which can provide a reasonable reference for the Ministry of Agriculture, food security departments and other government agencies, agri-food companies, and other organisations. Based on our assessment of GSC risk, we recommend the following optimisation strategies. (1) Consolidate the supply chain of food production safety and ensure that the red line of 1.8 billion mu of land in my country remains unshakable. Continue to implement agricultural supply-side reforms to ensure the quantity and quality/safety of food production. (2) The 'One Belt, One Road' policy is the basis for China's planned economic development in the future, and it is also an important means to improve the disadvantages of the trade environment in Northwest China. At the same time, the 'Belt and Road' connects more than 60 countries and regions in Central Asia, West Asia, and Eurasia. China's advocacy of the 'Belt and Road' can improve the food risks in China's provinces and improve countries' food problems along the route. Therefore, we must continue to advocate the construction of the 'One Belt, One Road' and international free trade zones, promote the diversification of food imports, improve the international food trade mechanism, enhance the attractiveness of China's business environment, and optimise the structure of the food industry. (3) According to local conditions, take measures based on the risk differences in each link of the inter-provincial grain supply chain (production, circulation, trade, and consumption). (4) The government should establish a transnational GSC early warning mechanism, cultivate competitive transnational grain merchants, and provide transnational logistics guarantees for effectively responding to crises and ensuring appropriate imports.

Food security is the foundation and guarantee of a country's national economic and political stability. The issue of food security is not a single issue. It is the safety of the production process from production, storage and transportation to circulation and consumption. The measurement of risks in the GSC is an important aspect of ensuring food security. Based on the panel data from 2003 to 2019, this paper constructs a food supply chain-based risk evaluation index system from four aspects of production, consumption, circulation, and trade, which can more scientifically reflect the GSC risk situation of different time series in various provinces in China. Based on different links of the GSC, this article builds a GSC risk evaluation index system from the four aspects of production, consumption, circulation, and trade, which is more scientific and comprehensive than previous studies. Food security is the bottom line for overall security and development. The research scale is selected at the provincial level, which highlights the coordination and circulation attributes of food security. Therefore, the research in this article has strong practical significance. In addition, this article is unique in that it focuses on the impact of trade on food risks and considers the importance of trade from three aspects: trade structure, trade volume, and trade scale. The results show that: (1) The overall risk of China's GSC remains stable, but individual provinces have higher risks than other provinces. (2) The risk value of my country's GSC shows obvious spatial differentiation in the four links of production, circulation, consumption, and trade. (3)

The distribution of risk value in the food supply chain shows obvious spatial aggregation characteristics. This article also has certain limitations. For indicator design, we only evaluate GSC risks from the four aspects of production, circulation, consumption, and trade. Primary data limit the construction of indicators, and the risk identification methods and research perspectives are relatively single, and some indicators may be due to different development stages of regional economic development. There are certain differences. There are many factors involved in the risk assessment of the GSC. The four aspects of production, circulation, consumption, and trade cannot cover all risk factors, such as the connection between different risk management methods and different risk factors. In terms of data processing methods, we only consider the entropy method and draw on the research results of relevant scholars. We have not tested the reliability of our method and other methods. The data processing methods of different scholars are slightly different, which will lead to slight deviations in the test results. We hope to solve these problems and conduct more in-depth analysis in future research, especially as the statistics of the food sector continue to improve.

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